Madroño, Vol. 58, No. 4, pp. 207–213, 2011

EFFECTS OF ERADICATION AND RESTORATION TREATMENTS ON ITALIAN THISTLE (*CARDUUS PYCNOCEPHALUS*)

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Abstract

Low elevation grasslands in California long have been dominated by Mediterranean grasses, but many areas still have large native forb populations. Alien forbs invade these grasslands, displacing both native and other alien species. Italian thistle is a noxious alien herb that has recently invaded these grasslands, including ungrazed blue oak (*Quercus douglassii*) and interior live oak (*Quercus wislizenii*) stands in Sequoia National Park. Here, Italian thistle tends to dominate under oaks and has the potential to substantially alter the foothill ecosystem by displacing native plants and acting as a ladder fuel that can carry fires into the oak canopy. We tested the effects of selectively reducing Italian thistle populations alone and in combination with restoration of native species. Two thistle eradication techniques (clipping and the application of clopyralid herbicide) and two restoration techniques (addition of native forb seeds or planting native grass plugs) were used. After two consecutive years of treatment we found: a) clipping was not effective at reducing Italian thistle populations (clipping reduced Italian thistle density in some areas, but not vegetative cover), b) herbicide reduced both Italian thistle density and vegetative cover for the first two growing seasons after application, but cover rebounded in the third growing season, c) native forb cover and species richness were not significantly affected by clipping or spot-treating with herbicide, d) the grass and forb addition treatments by themselves were not effective at reducing Italian thistle during the course of this study and e) sowing annual forb seeds after clipping resulted in greater forb cover and moderately reduced Italian thistle vegetative cover in the short term.

Key Words: Alien thistle, annual grasslands, blue oak, foothills, Italian thistle, native plant restoration.

Approximately 20% of California's 6550 plant species are naturalized non-natives (http://ucjeps.berkeley.edu/interchange) and 200 of these are considered to be invasive, having the ability to displace native species and disrupt ecosystem processes (Bossard et al. 2000). Low elevation grasslands and savannas are among the most highly invaded ecosystems in the state, and today they are dominated by a few species of non-native Mediterranean grasses and a mixture of native and non-native forbs (Heady 1988; Bartolome et al. 2007). These grasslands are vulnerable to additional invasions by alien forbs. Some of the more noxious species are the spiny Asteraceae such as thistles in the tribe Cynareae (Bossard et al. 2006).

Italian thistle (*Carduus pycnocephalus* L.), which is native to Europe and Asia, is a widespread noxious thistle with an annual or biennial life cycle in California annual grasslands and oak woodlands. It is particularly robust under blue oak canopies, suggesting it has high nitrogen and/or moisture requirements (Holm et al. 1997; Perakis and Kellogg 2007). Such invasions may threaten native understory species on these sites, which could be a particular concern if rare species occupy the same habitat. Dense Italian thistle populations with overlapping rosette leaves are capable of excluding native plant species by monopolizing light (Bossard and Lichti 2000). They also potentially affect wildlife movement due to deterrence from sharp spiny leaves and stems (Parsons 1973). Moreover, Italian thistle can potentially threaten oak trees, because, they can grow to 2 m and generate ladder fuels. Ladder fuels connecting surface litter to oak canopies during wildfires are a major contributor to blue oak canopy scorch and top-kill (Horney et al. 2002). The potential for Italian thistle to shade out native forbs, alter grazing patterns and convert surface fires into crown fires presents significant management concerns in the blue oak woodlands throughout the state.

When caught during their early phase of colonization invasive plant eradication may be feasible, but once established, they present formidable challenges for resource managers (DiTomaso et al. 2007). Methods aimed at eradication of invasive species may produce short term reductions in cover and density, but populations typically return once direct control ceases. One reason is that eradication methods can disrupt ecosystem processes and create disturbance sites for future colonization of invasive species (D'Antonio and Meyerson 2002). Also, even with precise treatments, eradication methods affect potential native competitors as well as other invasive species (DiTomaso et al. 2007). Non-native species thrive in California annual grasslands partially because these

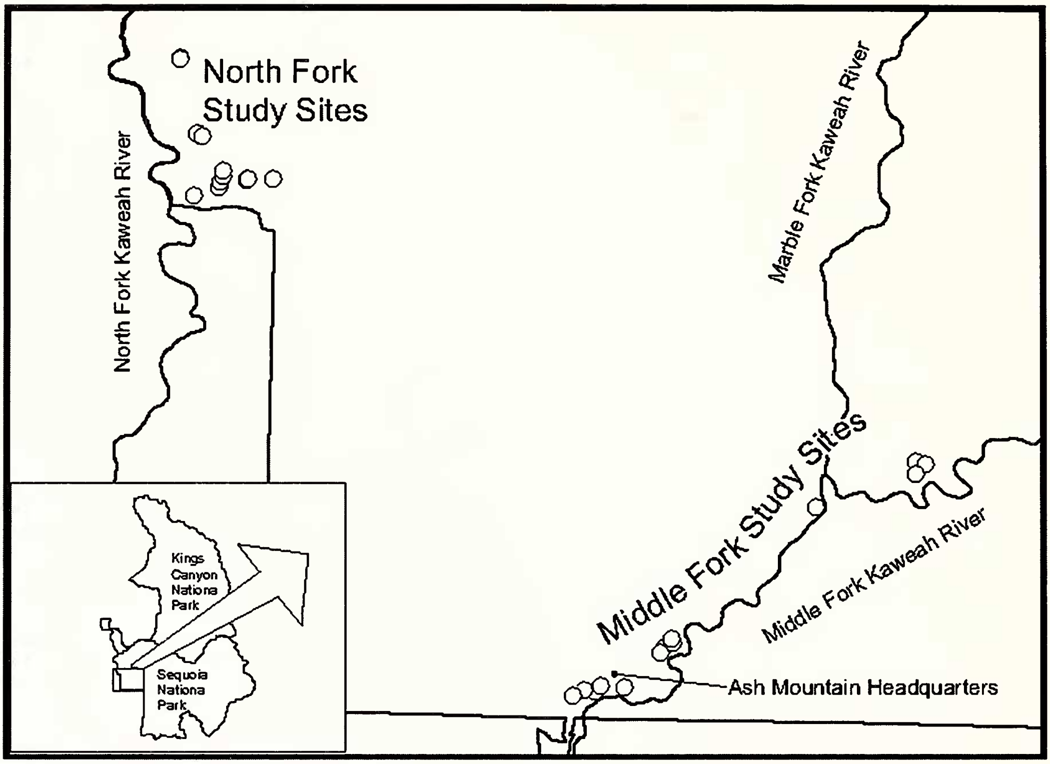

FIG. 1. Italian thistle study sites, Sequoia NP, California.

grasslands are highly disrupted ecosystems where the competitive balance between native species has diminished (Heady 1988).

In the Sierra Nevada foothills of Sequoia National Park, Italian thistle has been a persistent invasive and the target of eradication attempts since 2002. Typically resource managers have utilized two eradication treatments: spraying with the herbicide clopyralid and cutting or pulling (http://www.nps.gov/seki/naturescience/badcapy.htm). The present study was conducted to compare clopyralid and clipping and to couple these treatments with two restoration treatments (sowing native forb seeds or planting native perennial grass plugs) meant to increase potential native competitors. We hypothesized that suppression of Italian thistle would be best achieved by coupling eradication with restoration of native competitors. Results were determined over multiple years so that treatment longevity could be determined.

METHODS

Study Areas and Treatments

Our study was conducted between May 2006 and June 2010 in the Kaweah River watershed in the Sierra Nevada foothills in Sequoia National Park (Tulare County, California; Fig. 1). The vegetation was blue oak and interior live oak woodland and savanna; here cool wet winters and warm dry summers characterize its Mediterranean climate. Snow is uncommon in the foothills of the southern Sierra Nevada and therefore most precipitation is from rain. Except for the winter of 2009–2010, precipitation was at or below the 57 year average during this study (Fig. 2).

Using both National Park Service (NPS) maps and on-the-ground surveys of Italian thistles we established study sites throughout the 20 largest thistle populations in the park: 10 populations in the middle fork watershed and 10 populations in the north fork watershed. Within each of the two watersheds, 10 "canopy" sites were selected beneath the drip-line of blue oak, interior live oak or California buckeye (*Aesculus californica* [Spach] Nutt.) trees, at least 1 m from a tree bole. An additional 10 sites were selected outside the drip-line and were considered "open" sites. The amount of shading and solar intensity in both canopy and open plots varied widely due to aspect, canopy height and proximity to trees, shrubs and boulders. Each population consisted of several thistle patches located both beneath trees and in the open. Because most Italian thistle

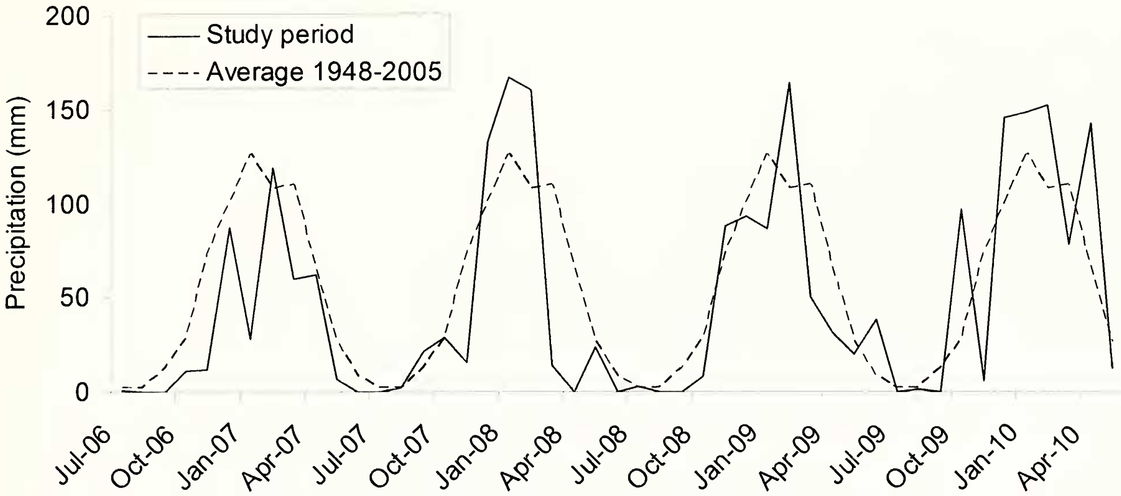

FIG. 2. Precipitation at Ash Mountain, Middle Fork Kaweah River, at the elevation of the study sites. Data collected by NPS and compiled by California Dept. of Water Resources (http://cdec.water.ca.gov/) and Desert Research Institute (http://www.wrcc.dri.edu).

patches were too small to fit all the treatment plots, few study sites were in a single patch; rather a site was defined as any number of nearby patches with similar slope position and substrate (i.e., a series of open or canopy patches along a single ridge or slope). Because all of the blue oak/interior live oak savannas in the park were easily accessed by roads and trails, there was no need to limit our selection based on access.

Nine 2 × 2 m plots were centered over the most densely populated thistle patches at each of the 20 sites. There were three eradication treatments (clipping, herbicide and no clipping or herbicide) fully crossed with three restoration treatments (native grass planting, native forb seeding and no planting or seeding) (3 × 3 = 9; Table 1). A buffer zone was created around each plot for walking between plots without disturbing the plots.

The clipping treatment was applied with a gas-powered line trimmer and was evenly applied near ground level to all non-woody plants in an assigned plot and its buffer zone. Clipped biomass was not removed.

Although herbicide treatments are often applied with broadcast spraying, our study treatment consisted of spot-treating Italian thistle plants with a 0.08% concentration of clopyralid and care was taken to target just thistles. This resulted in concentrations of herbicide commensurate with the density and size of the thistles during the two consecutive years that herbicide was applied. Clopyralid has both pre and post-emergent qualities. The herbicide is a plant growth regulator and is used to kill many forbs while not killing grasses and trees (DOW Agro-Sciences 1998). It is effective on species of *Asteraceae*, *Apiaceae*, *Caryophyllaceae*, *Fabaceae*, *Polygonaceae* and *Solanaceae* families (Rice and Toney 1996; Tyser et al. 1998; Reever-Morghan et al. 2003).

Clipping and herbicide treatments were applied early in the growing season during bolting to early rosette stage before peak flowering and before thistle seeds had dispersed. Clipping was applied in early May 2007 and 2008. Herbicide was applied in late April–early May in 2007 and 2008 (Table 2).

TABLE 1. ITALIAN THISTLE ERADICATION TREATMENTS (ROWS) AND SITE RESTORATION TREATMENTS (COLUMNS) IN SEQUOIA NATIONAL PARK. These treatments were replicated beneath tree canopy and in open grassland sites. [a]Forb seed treatment: 176 *Amsinckia menziesii* and 486 *Phacelia cicutaria* seeds per m^2. [b]41 *Melica californica* and 40 *Elymus trachycaulus* plants were one year old when they were planted 25 cm apart; some plantings were skipped due to rocks. The two species were planted on separate sides of the plot; each species was planted over a 1 × 2 m area. [c]Due to the nature of this clipping treatment, all grasses and forbs were clipped near ground level and biomass left. [d]Thistle plants were individually coated with 0.08% clopyralid (1.9 mL Transline®/L H_2O, or 1/4 oz/gal).

Thistle eradication treatment	Site restoration treatment		
	Control	Forb seed[a]	Planted grass[b]
Control	No treatment	Seeded only	Planted grass only
Clipped[c]	Clipped only	Clipped and seeded	Clipped and planted grass
Herbicide[d]	Herbicide only	Herbicide and seeded	Herb. and planted grass

TABLE 2. TIMELINE OF TREATMENTS (LISTED ABOVE) AND PLOT SURVEYS.

J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
2006	2007	2008	2009	2010

	Collect grass and forb seeds	Start grass plugs	Collect data, herbicide and clip	Seed forbs	Plant grass	Collect data, herbicide and clip (second treatment)	Collect data	Collect data

Seeds used for restoration treatments were collected separately within each watershed and within +/− 500 m elevation. Seed collection was during spring and summer 2006 (Table 2).

Grass plugs were propagated (shaded, misted and weeded) for one year in potting soil at the Ash Mountain greenhouses in Sequoia National Park (Table 2). The grass planting treatment was applied in late January through mid-February 2008 (Table 2). Potting soil was not removed while planting. Dibble tools were used to punch 4 × 15 cm holes in the ground to match the size of the grass plugs. The two grass species used in the restoration treatment were *Melica californica* Scribn. (41 one-year-old plugs spaced 25 cm apart) and *Elymus trachycaulus* (Link) Shinners (40 one-year-old plugs spaced 25 cm apart). Though planted on separate sides of the plots analysis was for the entire 2 × 2 plot, not for the individual grass species planted.

The native forb seed treatment was applied in mid-November 2007. Based on average seed weights, forb seeds comprised 180 *Amsinckia menziesii* (Lehm.) A. Nelson & J. F. Macbr. and 500 *Phacelia cicutaria* Greene seeds per square meter, which were mixed and scattered for a density of 680 seeds/m^2 in the assigned plots and buffer zone.

Data Collection and Analysis

Percentage vegetative cover of individual species within each plot was assessed in April–May 2009, using 1%, 5% and 10–100% in 10% increments (Table 2). Italian thistle cover was measured in April–June 2007–2010 and its density was measured in April–June 2009. Native grass density was assessed in April–June 2009.

Native forb cover in open sites, Italian thistle cover and native and alien species richness were analyzed with mixed effects models (SAS Institute 2007). Treatment and river drainage were fixed effects and site was the random effect. These models compared treatment effects across all sites independently for canopy and open sites. For a multiple year comparison of Italian thistle cover (2007–2010), canopy and open sites were combined. All mixed models were fitted using restricted maximum likelihood calculations. Denominator degrees of freedom were computed using the Satterthwaite approximation (Littell et al. 1996; SAS Institute 2007). Square-root and natural log transformations were used, when necessary, to correct normality and homoscedasticity. Tukey-Kramer tests were used to detect differences between treatment pairs.

Native forb cover in canopy sites, Italian thistle density, native grass cover and non-native grass cover could not be made normal and homoscedastic through transformation; therefore, for these variables the Kruskel-Wallis test was used instead of the mixed model and Nemenyi tests were used to detect differences between treatment pairs (Kruskel-Wallis tests were performed with SYSTAT 11 software and Nemenyi tests were calculated in a spreadsheet, as per Zar 1990). $P < 0.05$ was considered significant for all analyses.

RESULTS

Italian Thistle Cover and Density

In the short term Italian thistle density (Fig. 3) and vegetative cover (Fig. 4) were significantly reduced by herbicide treatment both under tree canopy and in the open (2009; two years after the initial treatment and one year after the follow-up treatment, see Table 2 for timeline). Coupling the herbicide treatment with a restoration treatment (seeding or planting native species) did not change the results for thistle density and cover in the short term. In the longer term (2010; three years after the initial herbicide treatment and two years after the follow-up herbicide treatment) the herbicide treatment alone did not significantly affect thistle vegetative cover, but the combined treatment of herbicide plus seeding resulted in lower thistle cover under tree canopy but not in the open (Fig. 5).

Clipping did not significantly affect thistle density or cover in the short term or long term when canopy and open sites were analyzed independently (Figs. 4 and 5) or combined (Fig. 6). Clipping combined with seeding was effective at reducing thistle cover in the short term only and only in canopy sites (Figs. 4 and 5).

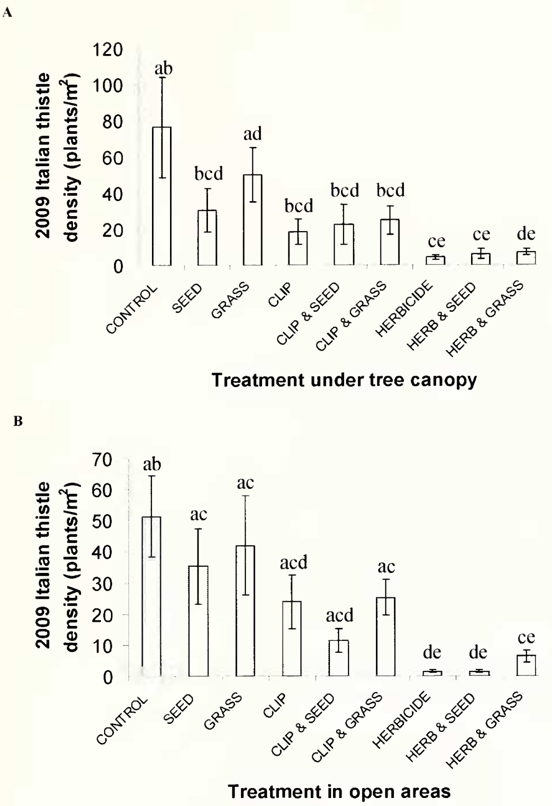

FIG. 3. 2009 Italian thistle density in canopy sites (A) and open sites (B) with respect to combinations of Italian thistle eradication (clipping and herbicide treatments in 2007 and repeated in 2008) and site restoration techniques (seeding and planting once in the winter of 2007–2008) in Sequoia National Park foothills. The same letter above bars indicates no significant difference at $\alpha = 0.05$.

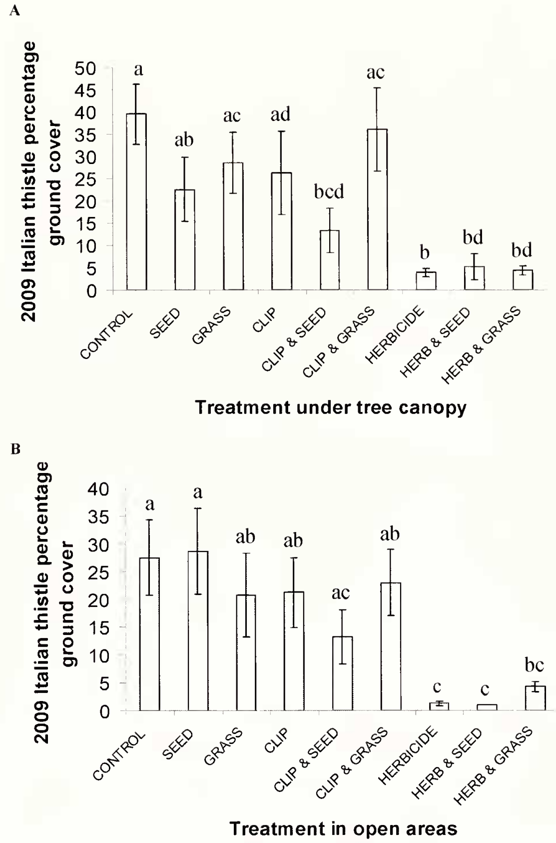

FIG. 4. 2009 Italian thistle vegetative cover percentage in canopy sites (a) and open sites (b) with respect to combinations of Italian thistle eradication (clipping and herbicide treatments in 2007 and repeated in 2008) and site restoration techniques (seeding and planting once in the winter of 2007–2008) in Sequoia National Park foothills. The same letter above bars indicates no significant difference at $\alpha = 0.05$.

Native Grasses and Forbs

Native grass plantings were not very successful due to extreme mortality in the first year, but native grass cover began to increase after the initial die-off. Only one third of plots that were planted had survivors after 1.5 years (June 2009), but one year later (June 2010) all of these plots still contained live native grasses.

Native forbs occurred in all but one of the study plots before the treatments and in all plots after treatments. In canopy sites in 2009, native forb cover was not significantly different in seeded versus control plots. In open sites, native forb cover was not significantly affected by any of the treatments. Native forb cover was not assessed in 2010.

Alien Grasses

Alien grass cover was only significantly affected by one of the treatments, and only in open sites in 2009; clipping plus planting native grass significantly reduced alien grass cover in open sites in 2009. The five most abundant alien grass species (by cover) in these plots were *Bromus diandrus* Roth (most abundant), *Avena barbata* Pott ex Link and *Bromus hordeaceus* L. (both species were equally abundant and together covered 15% less ground surface area than *B. diandrus*), *Avena fatua* L. and *Bromus arenarius* Labil. (both equally abundant and comprised 40% less ground surface area than *A. barbata* and *B. hordeaceus*). *Bromus diandrus* was the dominant alien grass species in canopy sites and *Bromus hordeaceous* was the dominant alien grass species in open sites. Cover of the other abundant grass species was not significantly different between open and canopy sites. In general, clipping reduced alien grass cover while herbicide increased it.

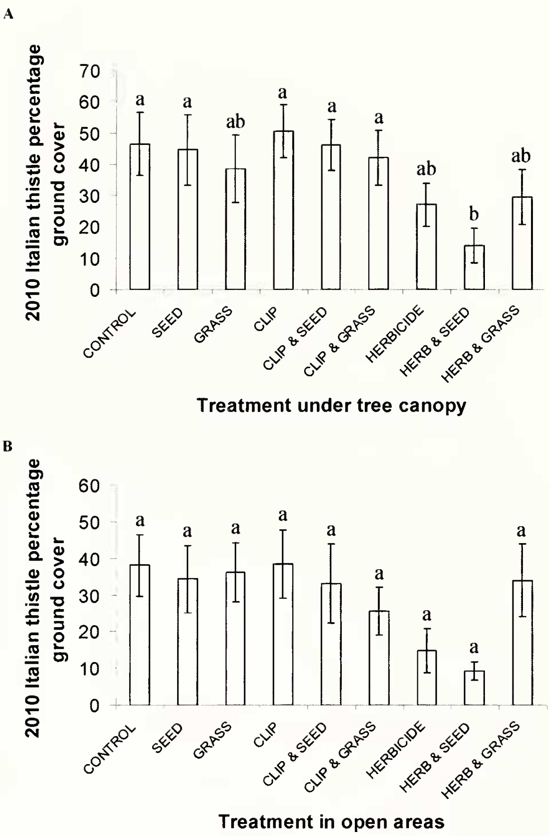

FIG. 5. 2010 Italian thistle vegetative cover percentage in canopy sites (A) and open sites (B) with respect to combinations of Italian thistle eradication Italian thistle eradication (clipping and herbicide treatments in 2007 and repeated in 2008) and site restoration techniques (seeding and planting once in the winter of 2007–2008) in Sequoia National Park foothills. The same letter above bars indicates no significant difference at $\alpha = 0.05$.

Species Richness

Native species richness the first year after all treatments were complete (2009) was not significantly different between treatments and controls in canopy or open sites. The controls had a mean of 4–5 species per 4 m^2 plot, while the treatments had 4–7 species per plot. Treatments with the greatest mean native species increases (2 more native forb species per plot than the control) were: clipped plus seeded plots in canopy sites and seeded, clipped plus seeded, clipped plus planted and herbicide plus seeded plots in open sites. Compared to the controls in both the canopy and open, alien grass and forb species richness was not significantly affected by any of the treatments.

Discussion

Spot-treating Italian thistle with the selective herbicide clopyralid was effective at controlling Italian thistles in blue oak and interior live oak savanna plots in the short-term; however, it was not effective at controlling thistles two years after treatments were stopped. Due to clopyralid's pre-emergent effect (DiTomaso et al. 2007) treatments applied in the spring one year controlled Italian thistle density and cover the next year, yet the *Carduus* seed bank can remain viable for 8–10 years (i.e., Burnside et al. 1996; Sindel 1997) and in order to be effective in the longer term, herbicide would need to be reapplied to draw down the seed bank. Unlike the herbicide treatment, clipping was not an effective eradication treatment even in the short-term.

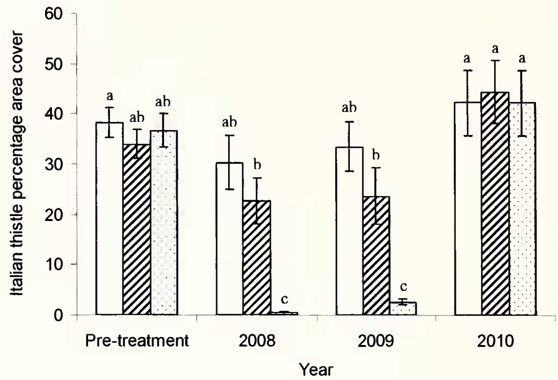

FIG. 6. Italian thistle percentage vegetative cover in control (white bars), clipped (striped bars) and herbicide-treated (dotted) plots from 2007 (pre-treatment) through 2010. Canopy and open plots are combined for this analysis. The same letter above bars indicates no significant difference at $\alpha = 0.05$.

Because Italian thistle seeds could eventually enter from outside sources and the fact that healthy native plant populations can resist aliens (Young et al. 2009), it has been proposed that eradication methods should be coupled with restoration treatments for the longest-lasting effect (D'Antonio and Meyerson 2002; DiTomaso et al. 2007). We hypothesized that suppression of Italian thistle would be best achieved by coupling eradication with restoration of native competitors, but we did not find sufficient evidence to support this hypotheses. Although clipping followed by seeding native forbs modestly controlled Italian thistle density and cover in canopy sites in the short term, it did not have an effect two years after treatment.

The other restoration treatment, planting native grasses, was also ineffective at reducing Italian thistle cover, at least in the few years of this study. Despite the low percentage of native grass cover and high mortality the first year, the fact that planting increased native grass frequency indicates that foothill sites currently devoid of native grasses could support these species, once established. Also, because perennial grasses grow so slowly in this environment longer term monitoring of this treatment might be useful. In these sites Italian thistle density and cover were stable over four years indicating that this species had saturated sites before our experiment began. Without intervention these populations are likely to remain as seed sources for further dispersal and will present formidable challenges for resource managers in the Sierra Nevada foothills. We recommend more research in the area of eradication combined with restoration so that an effective combination of treatments can be found. We learned that spot-treating with clopyralid was an effective short-term treatment, but we did not come up with a longer-term solution. Broadcast application of clopyralid would be easier to apply and would protect larger areas from reinvasion, but could potentially harm certain native plants; therefore, a study on the effects of this herbicide on native flora would be warranted.

Acknowledgments

Thanks to Julie Yee (Statistician), Matt Brooks (Research Ecologist) and Todd Esque (Research Ecologist) from the USGS Western Ecological Research Center for their helpful comments and advice on this manuscript. We thank Melanie Baer-Keeley, Amy Brown and John Nelson for their many hours of hard work throughout the project. Athena Demetry and Anne Pfaff assisted in the planning and logistics. The following people helped with the field work: Corie Cann, Pam Collins, Linda Franson, Lori Gant, Lee Goldstein, Marcia Goldstein, Sarah Graber, Jonathan Humphrey, Audrey Lucterhand, Kelly McGinnis, Kate McLaren, Liz Nanney, Anne Pfaff, Shelley Quaid, Dylan Schwilk, Christine Shook and Rich Thiel. We also appreciate the following SEKI divisions that provided help: Interpretation, Resources Management & Science, and Maintenance. Funding was from USGS Park-Oriented Biological Support. Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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